

Combustion and Fuels

Luke Cowell
Solar Turbines Incorporated

Overview

- **Gas Turbine Combustion Systems & Emissions**
- **Dry Low Emissions (DLE) Combustion**
- **Gas Turbine Fuels**
- **Future Combustion Technologies**

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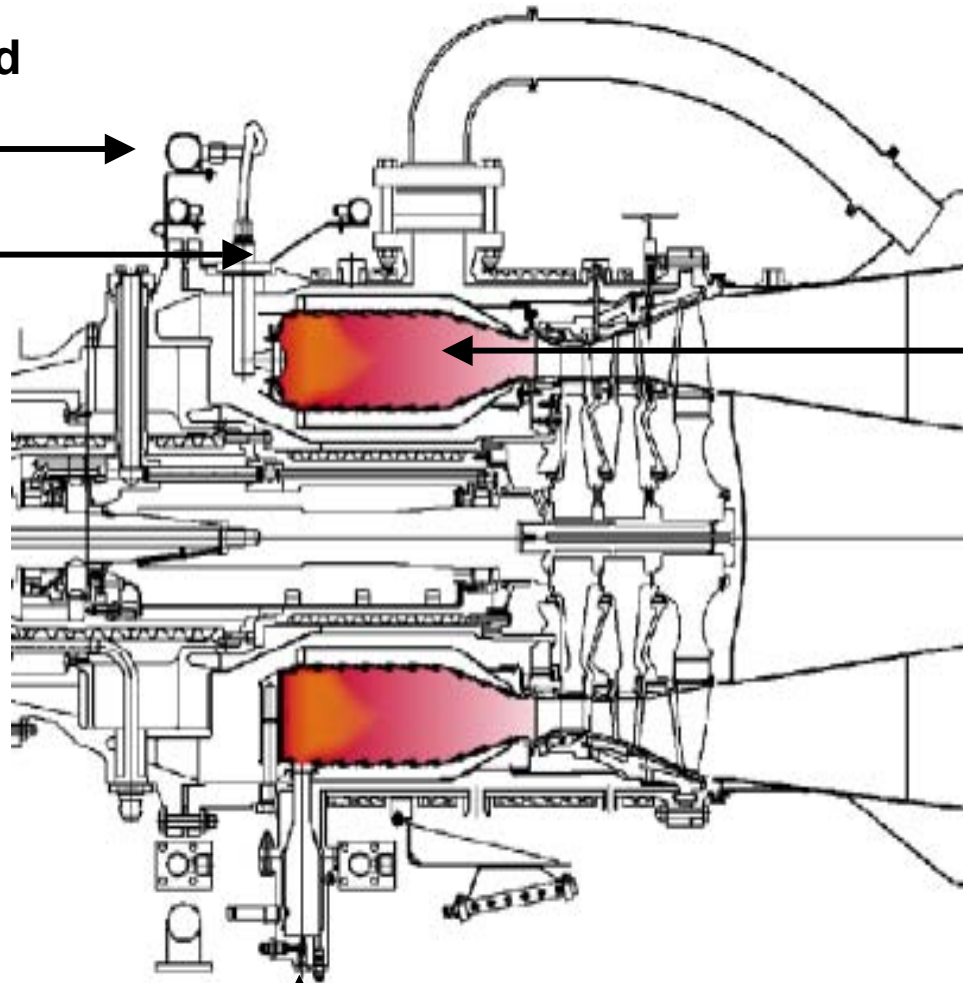
Typical Gas Turbine Combustion System

Fuel Supply Manifold

Fuel Injector

Annular
Combustor

Torch Igniter



Combustion System Design Criteria

- Reliable Ignition
 - Good Combustion Stability
 - High Combustion Efficiency
 - Low Smoke
 - Satisfactory Emissions Levels
 - Minimum Pressure Loss
 - Satisfactory Combustor Exit
 - Temperature Distribution
 - Life
- Operation**
- Environmental Regulations**
- Performance**
- Durability**

Industrial Gas Turbine Combustion Systems

- **Conventional Combustion**
 - Diffusion Combustion
 - Historical Design
- **Dry Low Emissions (DLE or DLN) - “SoLoNOx”**
 - Lean Premixed Combustion
 - Superior Emissions Performance
 - Offered Since 1992

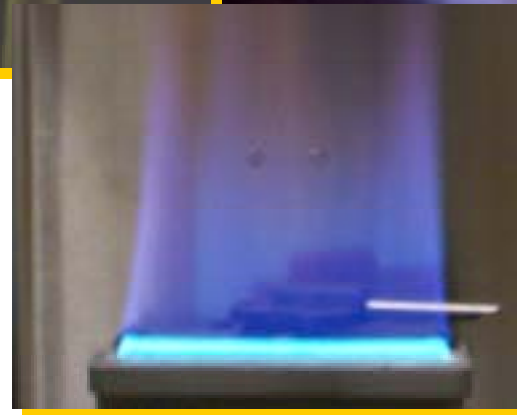
Diffusion Flames

Fuel and Air Mix and Burn At
the Same Time

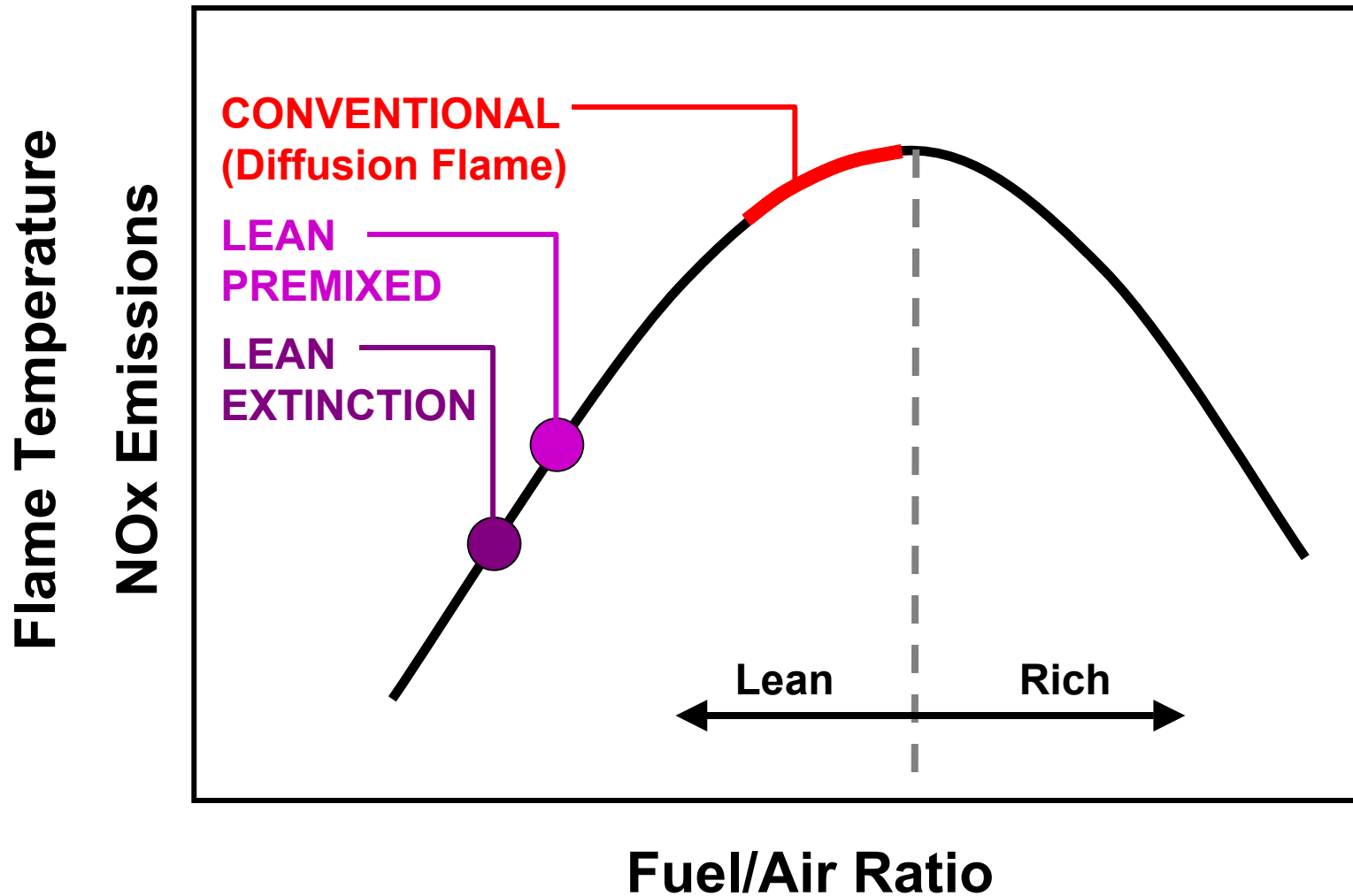


Premixed Flames

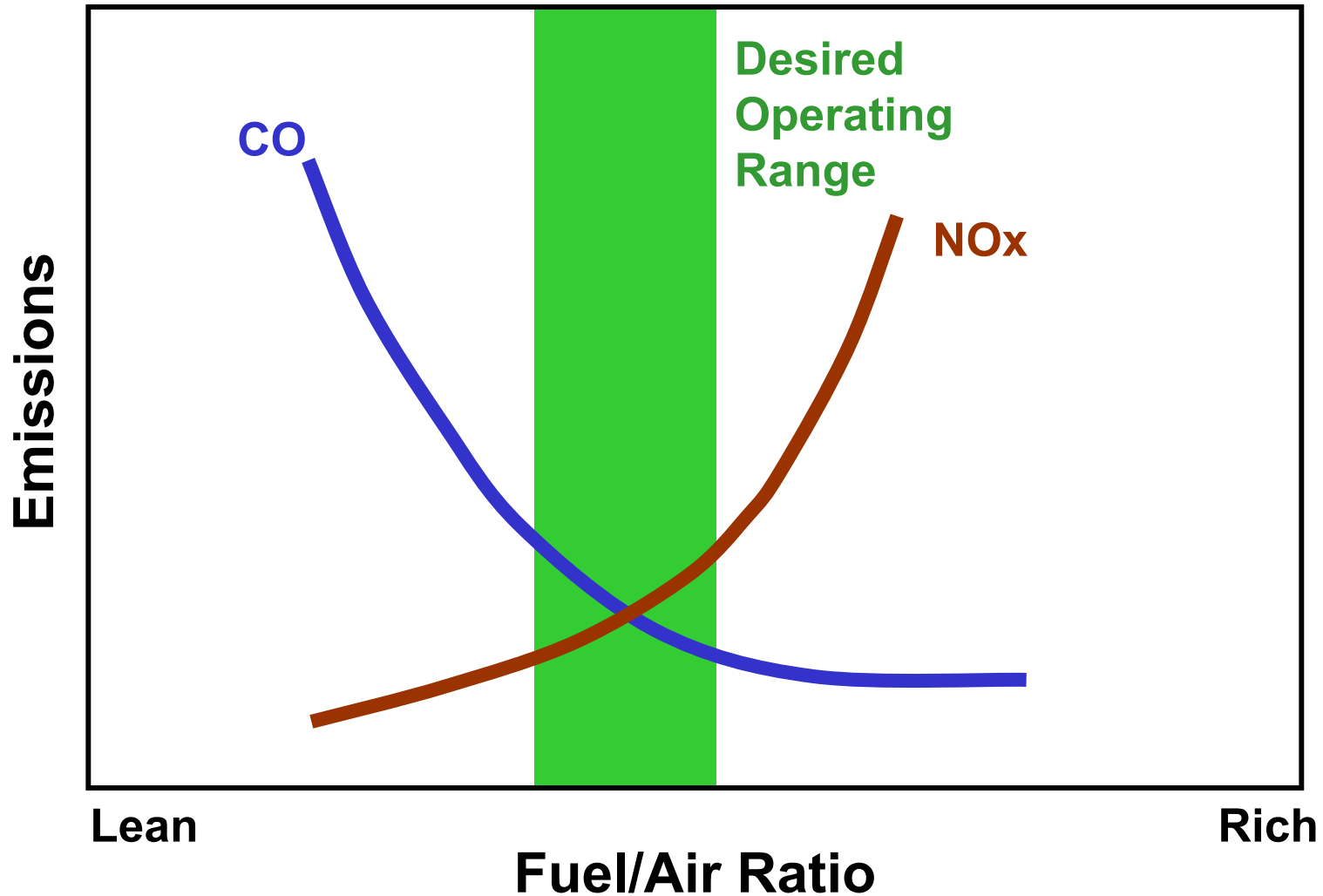
Fuel and Air Mix and Then
Burn



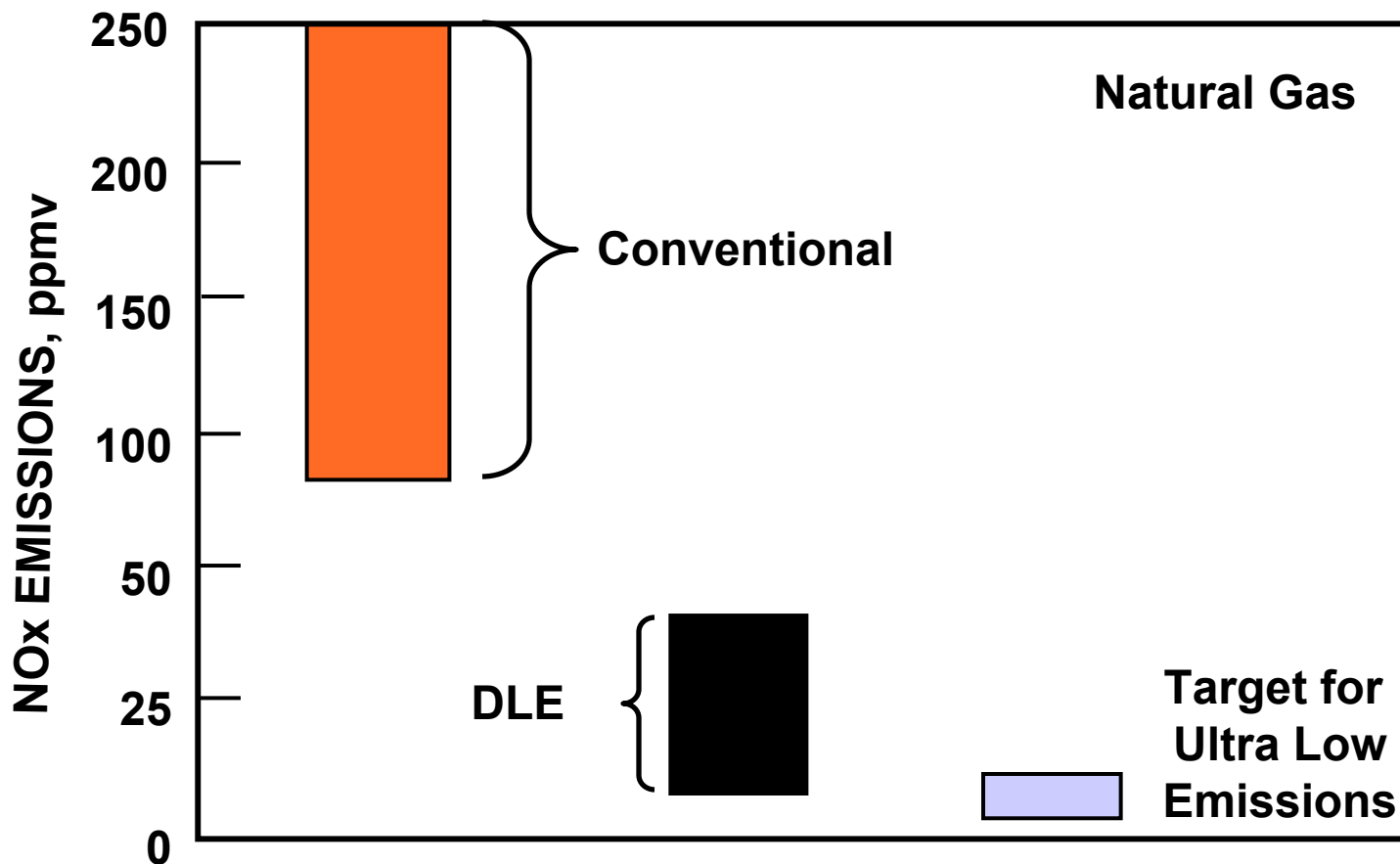
Effect of Stoichiometry on Flame Temperature and NOx Emissions



Emissions Characteristics



Combustion System NOx Emission Capabilities



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DLE is Pollution Prevention

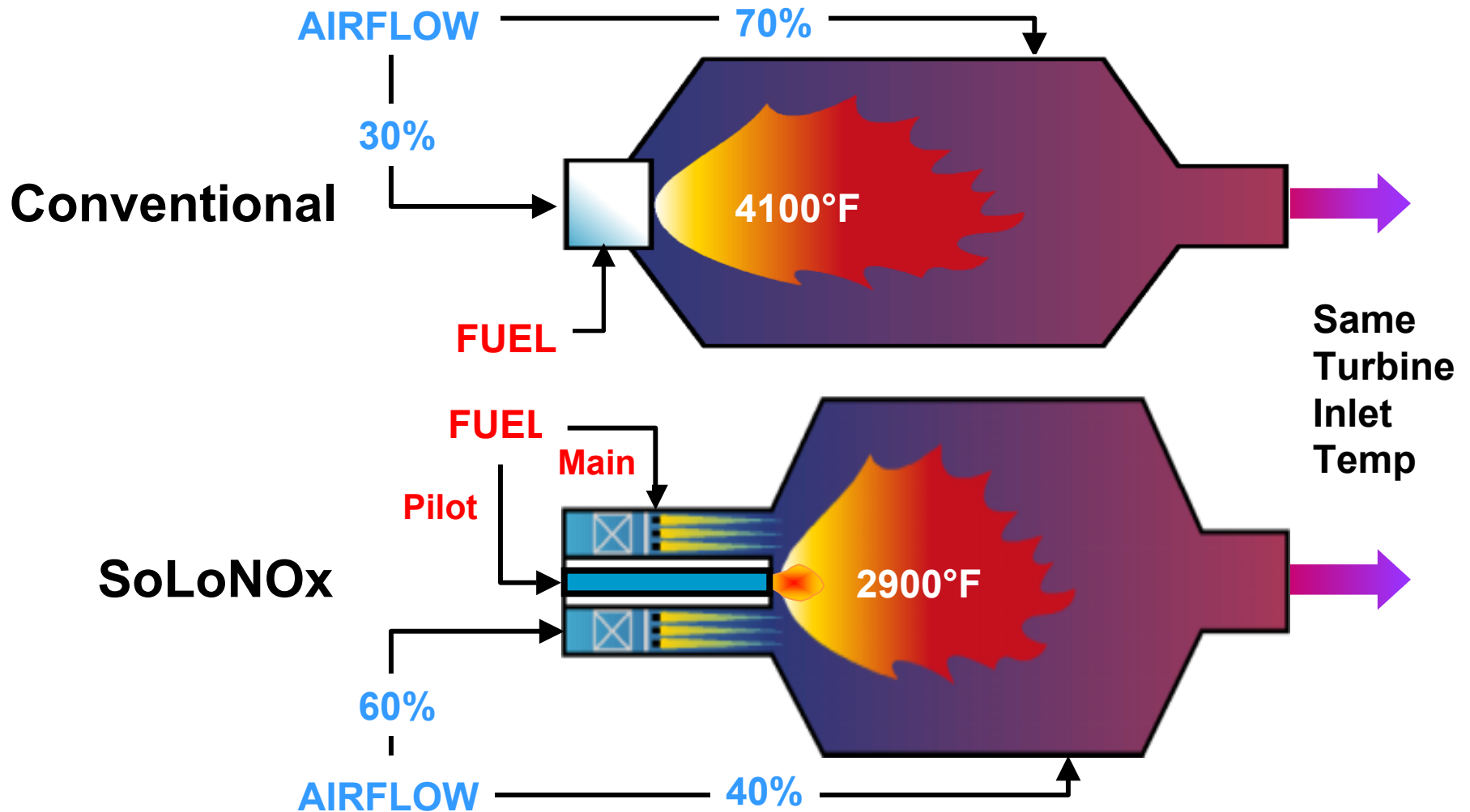
***Reduction of Combustion-Generated
Exhaust Emissions through
Understanding and Control of
Combustion Process***

More Cost-Effective Than Exhaust Clean Up

- **Lean Premixed Combustion Reduces NOx, CO and UHC Emissions**
- **NOx are Reduced**
 - Lowering Flame Temperature
 - ◆ Lean Combustion
 - ◆ Premixing to Eliminate “Hot Spots”
- **CO and UHC are Reduced**
 - Increasing Combustion Residence Time (Volume)
 - Combustor Design to Prevent Local Quenching

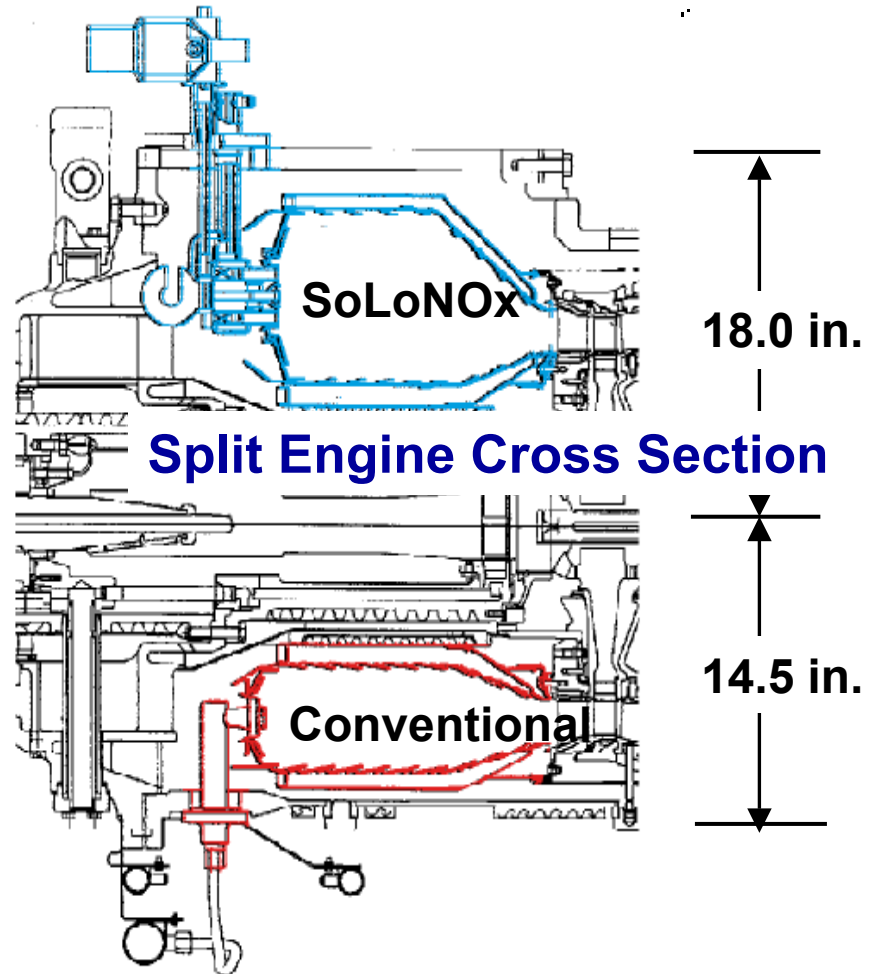
Solar Turbines

A Caterpillar Company



SoLoNOx Engine and Package Changes from Conventional Combustion Systems

- Combustor Liner
- Fuel Injectors
- Engine Casings
- Fuel System
- Control System





- **Lean Premixed Combustion**
- **Diesel No. 2 and Kerosene**
- **Main and Pilot Fuel Circuits on Both Fuels**
- **Same Combustor Liner as Gas Only**

- First Unit Commissioned 1992 for 42 ppm on Gas
- First Dual Fuel DLE Unit Commissioned in 1994
- Units Capable of 25 ppm Ship in 1995
- Units Offered at 15 ppm or Less (with restrictions) in 2000
- Estimate >1400 DLE Units* Worldwide
- Nearly 1000 SoLoNOx Units Sold**



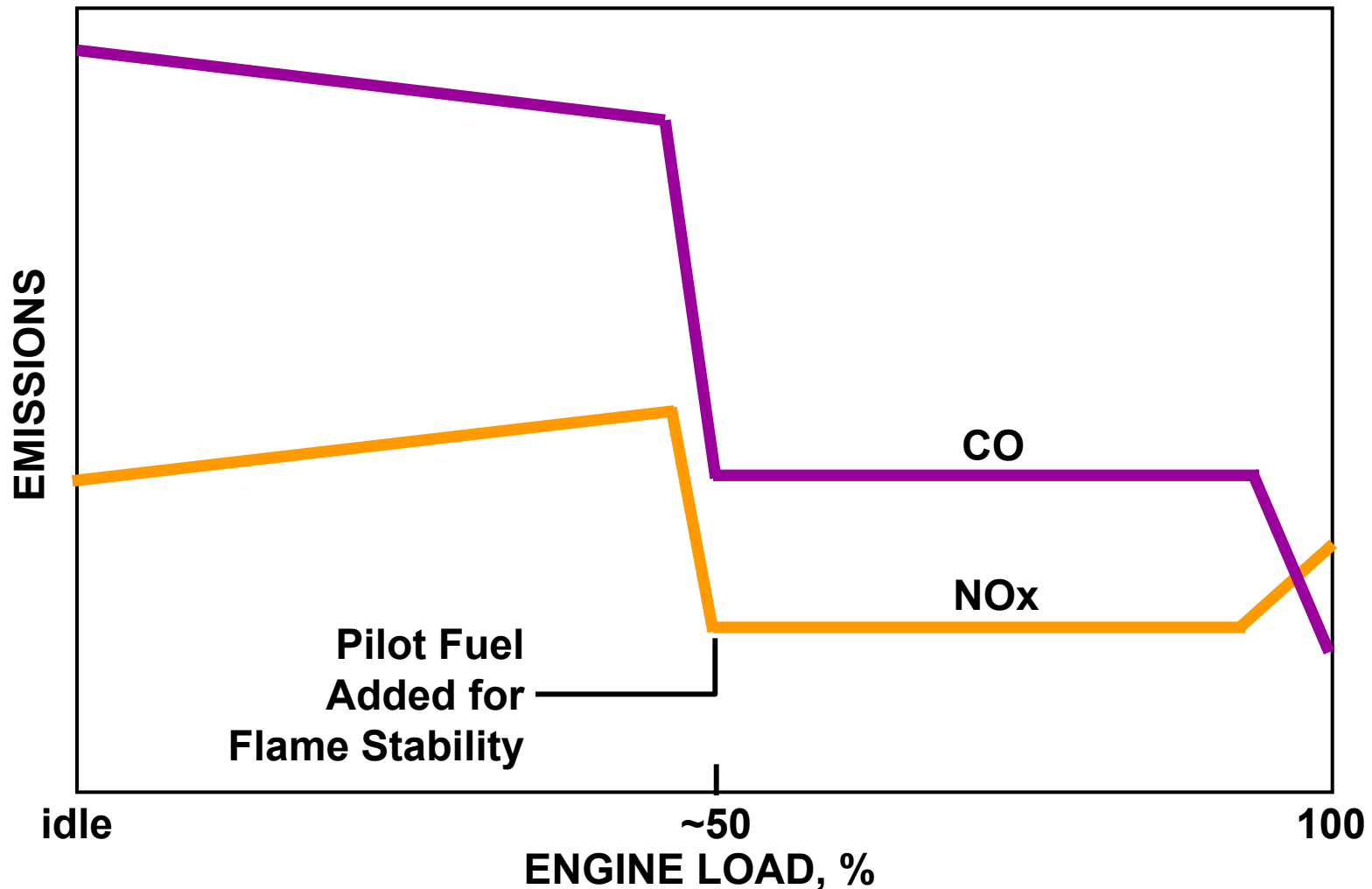
*** <30,000 Hp**

**** Solar Turbines Only**

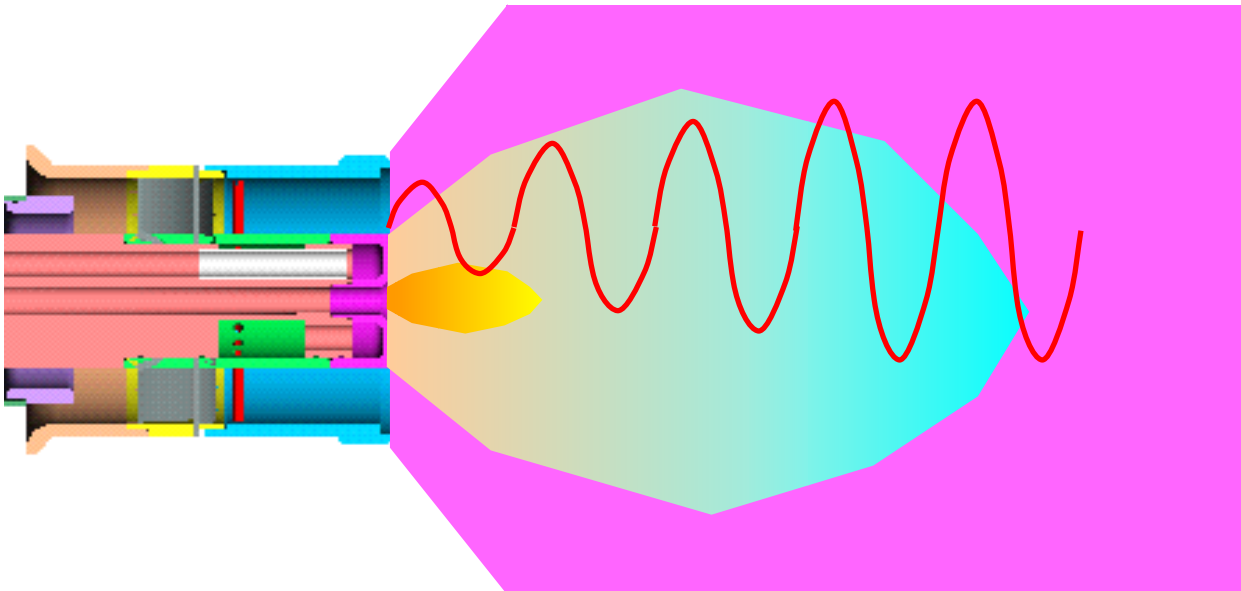
Operation and Conditions That Increase Emissions on DLE Units

- **Low Load and Load Transients**
- **Fuel Type and Quality**
- **Combustor Induced Pressure Oscillations**
- **Extremely Cold Ambients**

General Trends for NOx, and CO



- Potential in All Lean-Premixed Combustion Systems
- Oscillations Present When Fuel Heat Release in Phase with Combustor Acoustic Frequency
- Rumble is Lower Frequency Flame Instability

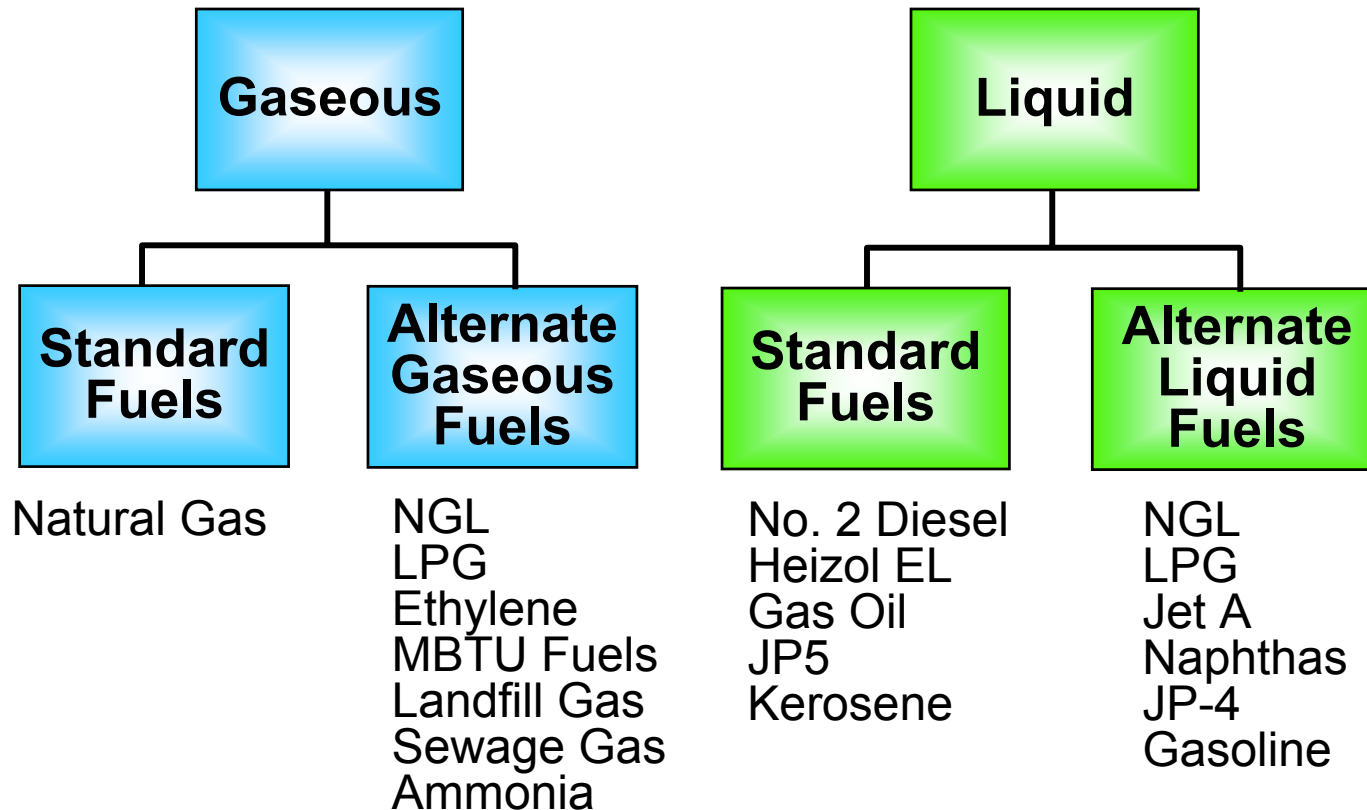


Current SoLoNOx Operation Below 0°F (-18°C)

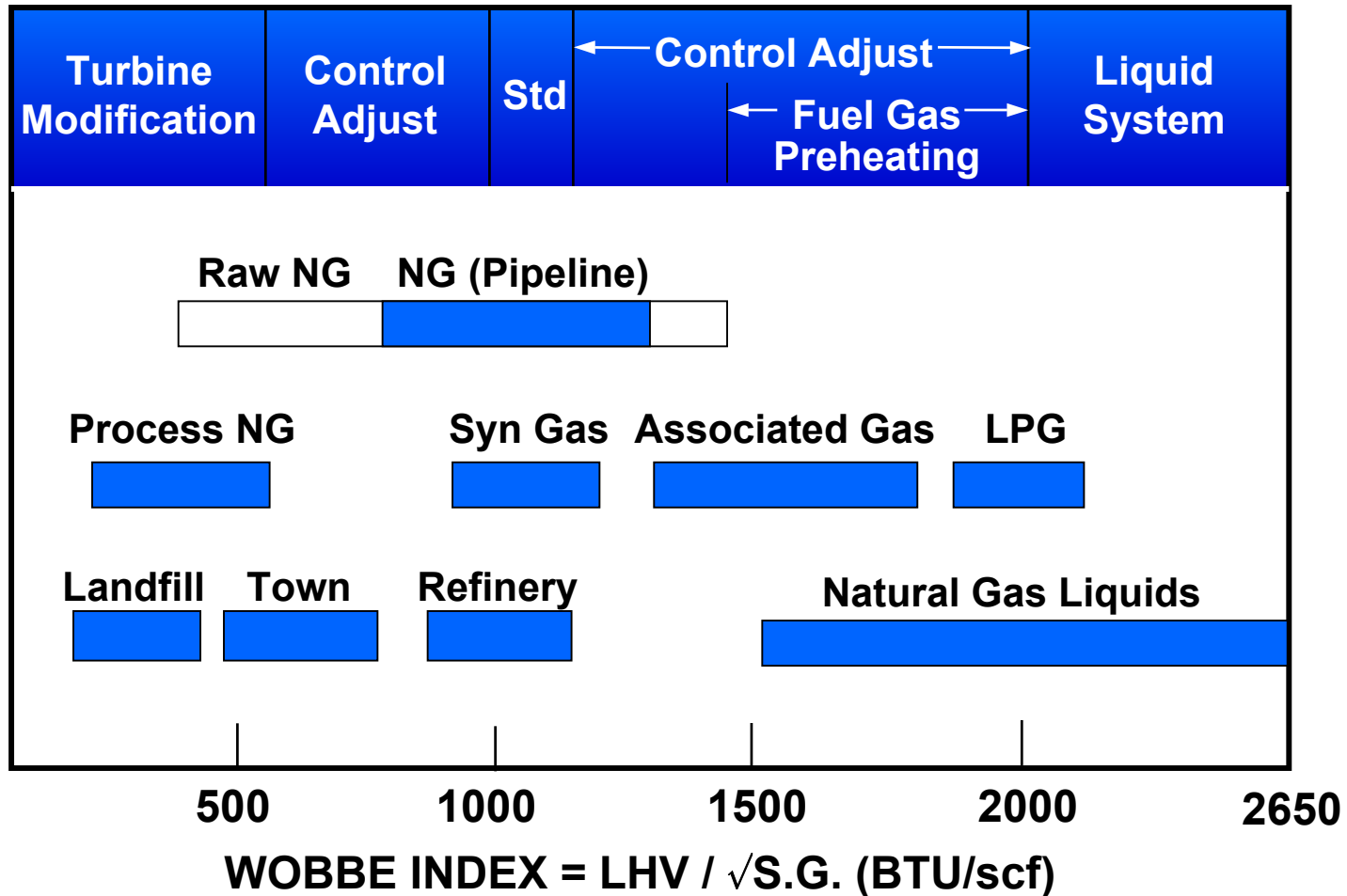
- **Engine Operation Not Impacted**
- **Pilot Increases to Control Rumble and Prevent Flameout on Some Engine Models**
- **NOx and CO Emissions Increase**
- **Development in Progress To Reduce Emissions**

Overview

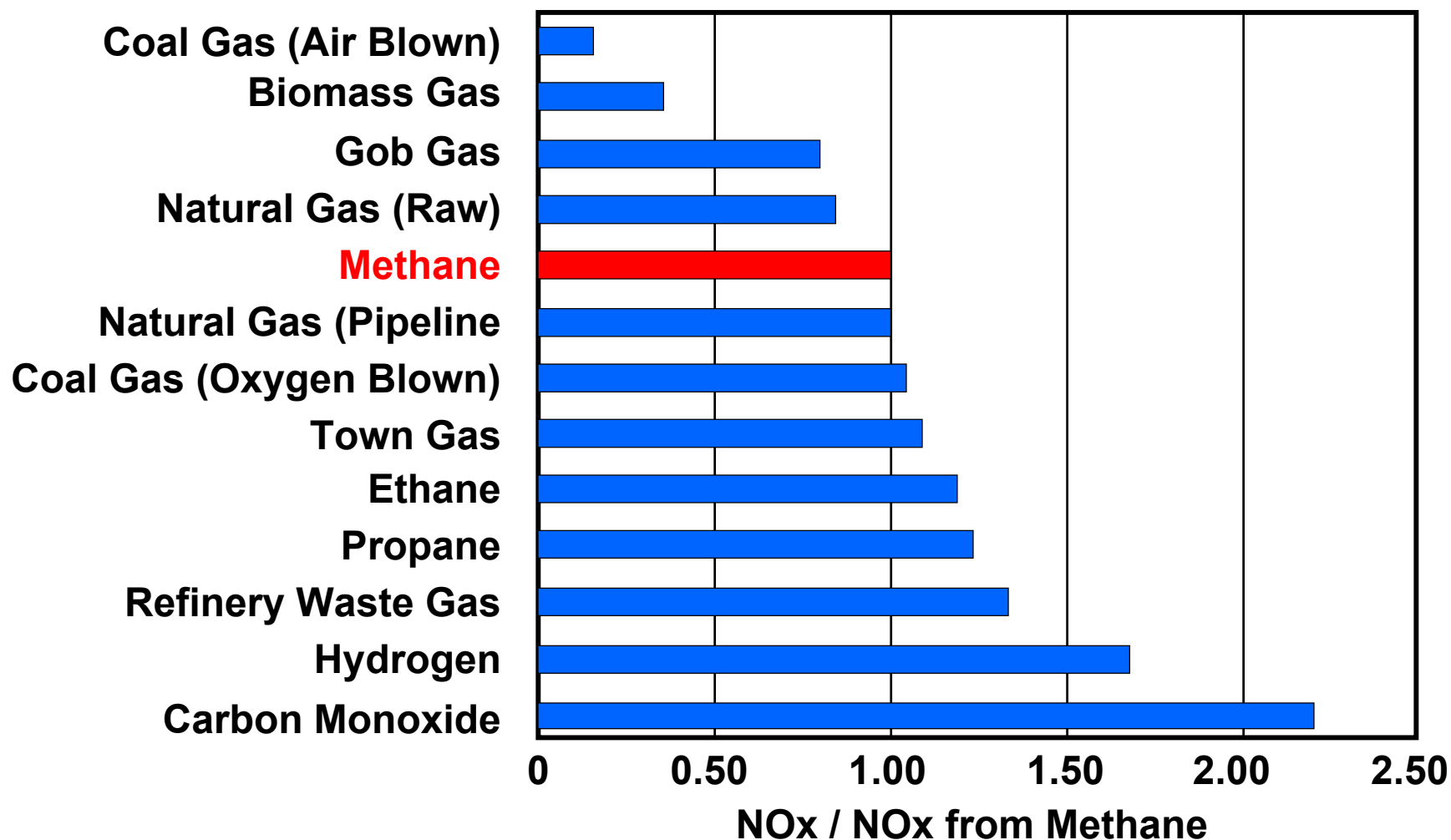
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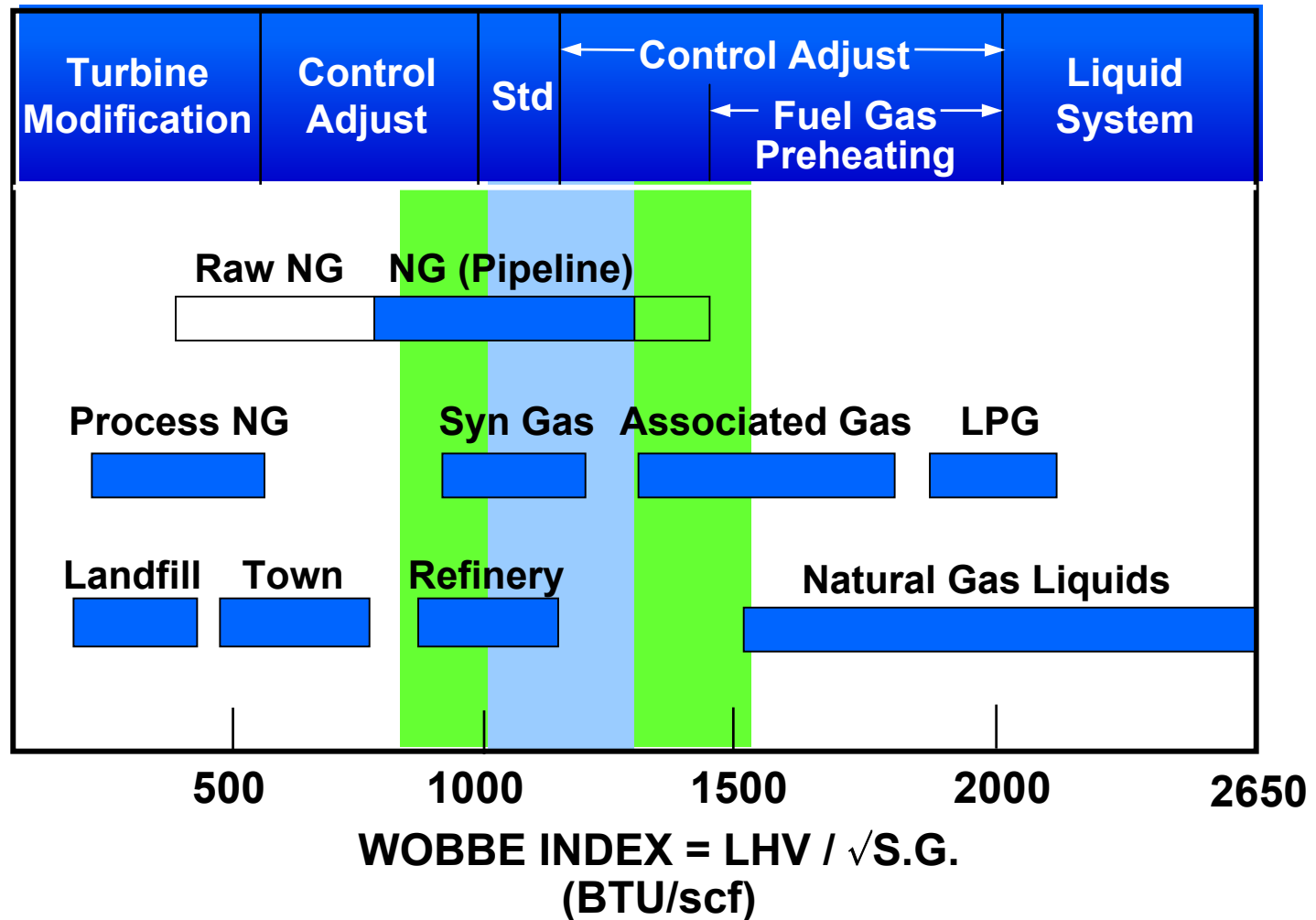
Impact of Gas Fuel Energy Content on Conventional Gas Turbine and Control Systems



Effect of Gas Fuel Type on NOx Emissions



DLE Gas Turbine Range



Potential Effect of Fuel Type on DLE Turbines

- **Durability**
 - Autoignition
 - Flashback
 - Oscillations
 - Contamination
- **Emissions**

Fuel Quality

- **Gas Fuel - Natural Gas**

- Fuel Variability: Wobbe of $1220 \pm 10\%$
- Gas Supply Temperature $> +50^{\circ}\text{F}$ (10°C) Dew Pt
- No Liquids Allowed in Fuel Gas
- Particulate Limits

- **Liquid Fuel**

- Viscosity
- Distillation
- Particulate
- Contaminants (Rust, Water, Salt, Others)

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Developments For Lower Emissions with Lean Premixed Combustion Systems

- Combustor Liner
- Advanced Injectors
- Controls Technology
- Reducing Manufacturing Variations



- Technologies to Allow Combustion at Lower Flame Temperatures
- Potential for Low Single Digit NO_x Levels

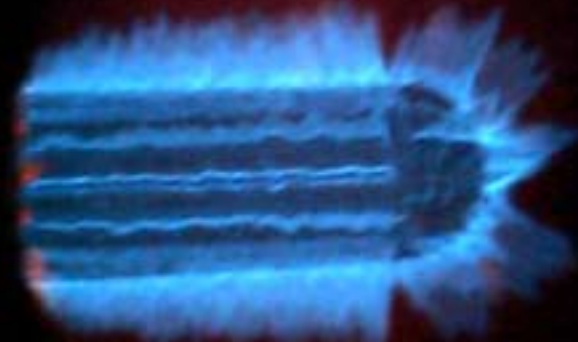
Lean Catalytic Combustion



Rich Catalytic Combustion



Surface Combustion



- **Conventional Combustion Systems Offer Maximum Turbine Operation and Fuel Flexibility**
- **DLE Gas Turbines Have Been Successfully Introduced**
- **DLE Offers Ten Fold Decrease in Turbine Emissions**
- **Cost Effective Compared to Exhaust Clean-Up**
- **DLE Presents Turbine Operators with Some Limitations**
- **Potential to Reduce Emissions Further**



Questions?